

Investigation of Microstructure and Transport in Stably Stratified Turbulent Shear Flow

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LONG-TERM GOAL

Our long term goal is to provide fundamental experimental and computational understanding of the evolution of turbulent mixing in a stratified fluid which will serve as a sound basis for interpretation of ocean measurements, particularly those determining ocean microstructure stirring and mixing.

OBJECTIVES

Our objective is to quantitatively determine the full energy balances in evolving or steady state stably stratified turbulent shear flows, including determination of effective eddy diffusivities. These can serve both as diagnostics for small scale ocean microstructure measurements and can provide realistic, buoyancy influenced eddy diffusivities and more sophisticated transport models which can serve as necessary small scale input modeling larger scale modeling such as ocean circulation and ocean climate models.

APPROACH

The emphasis of our experimental approach has evolved to making rapid vertically sampled measurements of temperature and velocity in order to more closely approximate the sampling techniques by which oceanographers obtain most of their data. These measurements, combined with our usual Eulerian measurements of velocity and density fluctuations, momentum and buoyancy fluxes, provide a simulation of ocean measurements within a well defined and characterized stably stratified turbulent flow, which is not possible to document to such a degree under ocean conditions. Progress toward this goal has been described in Keller and Van Atta (1998), while application of the earlier Eulerian lab and computational data to an extension of the Osborn-Cox model has been described in Van Atta (1998).

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The direct numerical simulation (DNS) approach has been used to perform highly resolved, three-dimensional, unsteady simulations of stratified turbulence. The previous simulations of stably stratified flow with vertical shear dU/dz have been extended to include an additional horizontal shear component dU/dy . The object is to study the effect of horizontal shear on vertical transport, a subject which has attracted little interest in the past. In the deep ocean, vertical shear is dominant; however, in coastal regions, straits, fronts, and in the presence of bottom topography, the dU/dy component may be comparable and therefore deserves study.

WORK COMPLETED

A rapidly sampling vertical profiler has been designed, built, and tested. The profiler has proven to be an effective device for obtaining nearly instantaneous vertical profiles of density fluctuations. Vertical density profiles along with extensive supporting Eulerian data have been obtained for one case of a nearly neutral shear flow in which the Richardson number takes the critical value and assumptions of the Osborn-Cox model are satisfied. We are currently extending these data to growing and decaying shear flows for sub and super critical Richardson numbers. The quality of the data obtained to date is good and the data awaits further processing.

Three DNS studies have been completed in the past year and data on turbulent dissipation rates, mixing coefficients and buoyancy fluxes obtained. In the first study reported by Jacobitz and Sarkar (1998a), the magnitude of dU/dy has been increased relative to dU/dz keeping the magnitude of total shear and vertical stratification constant. In the second study, the case of pure horizontal shear has been examined for a wide range of values of gradient Richardson numbers as described by Jacobitz and Sarkar (1998b). Finally, the effect of shear number on the turbulence evolution has been revisited by Jacobitz and Sarkar (1998c).

RESULTS

Initial experimental results for the critical Ri number flow include the finding that the turbulent density field is nearly isotropic, as vertical ("dropped") spectra of density coincide closely with horizontal Eulerian ("towed or moored") spectra. The data show overturning "patches" in the profiles similar to those observed in ocean data in which the density field is overturning. Direct numerical simulations of our flow fields also show similar patchy regions of high vorticity and overturns (Diamessis and Nomura, 1998).

DNS gives a new result in stratified flows: for the same magnitude of mean shear, vertical transport and mixing efficiency is larger if the shear is in the horizontal direction, dU/dy , rather than being vertical, dU/dz . Furthermore, a relatively small magnitude of dU/dy compared to dU/dz causes a large change in the transport coefficients.

IMPACT/APPLICATION

The comparison of vertical and horizontal density spectra results show that for a homogeneous stably stratified turbulent shear flow, which is stationary in time (or space) (the basis of the Osborn-Cox assumption), the density field is nearly isotropic so that the full assumptions of the Osborn-Cox formulation are satisfied and the method may be relied upon in ocean measurements to give good estimates of scalar dissipation and density fluxes. However, when the homogeneous turbulence is decaying, the scalar isotropy assumption is found to be inaccurate, and the non-steady state

amendments of Osborn-Cox relation must be taken into account to obtain accurate buoyancy flux estimates.

Oceanic flows have complex mean velocity variations especially if boundaries are present. The DNS study provides fundamentally new information on the effect of such non-vertical mean velocity gradients on the microstructure.

TRANSITIONS

Our results can be used by oceanographers to provide insight into ocean mixing process and to make more accurate measurements of ocean turbulence and mixing. Ocean microstructure probes are currently being developed by several groups which in principle will be able to simultaneously measure all the necessary governing parameters as revealed by the lab experiments and direct numerical simulations.

RELATED PROJECTS

Extensive measurements of characteristics of quasi periodic (Brunt-Vaisala frequency) energy exchange between turbulent kinetic energy and fluctuating potential energy (density fluctuations) have been made in our lab for unsheared stably stratified turbulence. This very basic, but non-funded, work is being done by a Japanese exchange student with a one-year scholarship from the Japanese government. Comparisons are being made with direct numerical simulations of Gerz and Yamazaki (1993) and with more recent analytical work by Hanazaki and Hunt (1996).

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